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DATE - June 8, 1965

MANUAL SHELTER-VENTILATING DEVICES FOR CROWDED SHELTERS COOLED BY OUTSIDE AIR--A PRELIMINARY REPORT*

Cresson H. Kearny

ABSTRACT

A recently invented shelter-ventilating punkah-pump which enables one person to pump manually over 5000 cubic feet per minute of air into a shelter can be made in home workshops using locally obtainable materials. A person with a few tools also can build efficient new directional-punkahs which can be used to cause directed air flows within a shelter of up to 10,000 cubic feet per minute and simultaneously to fan the shelter occupants. Thus, even in the hottest summer weather in the United States, the occupants of a crowded shelter can function as efficient evaporative coolers cooled by the evaporation of sweat, provided they also have adequate drinking water and salt.

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I. THE PROBLEM

Contrary to the beliefs of many air-conditioning specialists, mechanical refrigeration is not required in order to maintain tolerable conditions in crowded, long-occupied shelters, even during periods of extreme summer heat, provided that:

1. Sufficient outside air--up to as much as 30 cubic feet per minute per occupant during hot weather in the regions of highest effective temperatures--is pumped into the shelter.

2. This air is distributed uniformly within the shelter.

3. This air is moved close to the skins of shelter occupants at sufficiently high velocities to evaporate their sweat efficiently and thus, if need be, to remove all body heat solely by latent cooling due to the evaporation of sweat. Under such extreme conditions, four or five quarts of water per day per occupant are required--the same, as would be expected, as the daily water ration per slave stipulated by the laws which governed ships engaged in the regulated slave trade.¹ For if a person produces 400 BTU per hour and since the latent heat of vaporization of one pound of water is roughly 1000 BTU, therefore one pound of sweat, if evaporated efficiently on his bare skin, will cool this person for $1000/400 = 2.5$ hours. Furthermore, a nonacclimated person sweating this much should take $1/3$ ounce of salt per day.

Before describing some new manual air-moving devices which satisfy the requirements of even these most difficult shelter habitability problems, let us first consider some means by which natives have learned to use hot and humid air in order more successfully to keep themselves tolerably comfortable.

¹Albert Biderman, Margot Louria, and Joan Bacchus, Historical Incidents of Extreme Overcrowding, Bureau of Social Science Research, Inc., Washington, D. C., BSSR:354-5 (March 1963), p A-17.

II. METHODS USED BY JUNGLE NATIVES IN EXTREMELY HOT AND HUMID WEATHER

1. Using simple punkahs to fan their bodies.

In the Far East even some primitive peoples use simple punkahs to stir the air in a room back and forth and thus to cool persons below them by producing moving-air conditions over their bodies. These simple punkahs are merely light, solid panels which are hung from the ceiling and which swing pendulum-like when pulled via a pull-cord by a servant, who often simultaneously operates several punkahs in different rooms.

2. Insuring that sufficient naturally moving air reaches their bodies.

In those areas of the Orinoco and Amazon basins which experience such high humid temperatures that practically all body heat must be eliminated by the evaporation of sweat, jungle natives during the hottest part of the day usually lie quietly, almost nude, in open-weave, net-like string hammocks hung in the shade of open-sided, elevated-floored huts with thick thatched roofs. Thus these jungle people enable what little naturally circulating air there is to move over practically all their skins and to evaporate efficiently almost all their sweat.

III. MANUAL VENTILATING PUMP DESIGN FOR 30 CUBIC FEET OF AIR PER MINUTE PER OCCUPANT OF LARGE SHELTERS

1. Basic Principles of Manual Shelter Ventilating Pump Design

Presently available commercial manual ventilating pumps are not practical means during periods of high effective temperatures for ventilating typical large shelters designated for hundreds of people. Such pumps require too high expenditures of energy per cubic foot pumped, primarily because they are not designed to take advantage of the full cross-sectional areas provided by doorways, stairways, and elevator shafts of typical fallout shelters. No commercially available one-man manual air pump can deliver thousands of cubic feet per minute.

Before discussing the construction of two new types of simple, cheap, efficient, manual pumps designed to ventilate large shelters, it is well to consider some basic principles which govern efficient shelter pump designs:

1. Air velocities at all points in the air intake passageways, in the pump itself, and in the exhaust passageways should be kept as low as possible. As a specific example, consider a shelter with its minimum cross-sectional area (in any part of its air-flow passageways) being a typical 6-1/2-by-2-1/2-ft doorway. Let us consider two different pumps which could be used to ventilate this shelter:

- a. Any pump which causes air to flow through a minimum 2-ft-diam opening (such as the cowl of a 2-ft-diam fan), i.e., through a 3-sq-ft opening.

- b. A punkah-pump (see Fig. 1) which is operated in this 6-1/2-by-2-1/2-ft doorway and which pumps air through essentially its entire 15-sq-ft opening. (Such a pump is shown during testing in Fig. 2.)

If both of these pumps move the same volume of air per unit time, then the velocity of air flow through the 2-ft-diam opening is 15 sq ft / 3 sq ft = 5 times the velocity of the same volume of air pumped through the 15-sq-ft doorway opening. And the kinetic energy ($\frac{1}{2}mv^2$) of this same volume of air with 5 times as high velocity is $(\frac{1}{2}m \cdot 5^2) / (\frac{1}{2}m \cdot 1^2) = 25$ times as great. Thus, even if mechanical efficiencies are 100%, the high velocity pump (which forces an equal volume of air through a 3-sq-ft opening) must do 25 times as much of the work (to meet unavoidable kinetic energy demands) as must be done by the low-velocity punkah-pump which takes full advantage of the available large cross-section areas in the shelter air-flow passageways.

Of course the larger pressure-head losses caused by eddy currents, turbulence, drag, etc., at five times as high air velocities contribute even more than do kinetic energy requirements to the total work necessary to pump a given volume of air at higher velocities. Standard engineering tables listing head losses (work requirements), such as appear in the

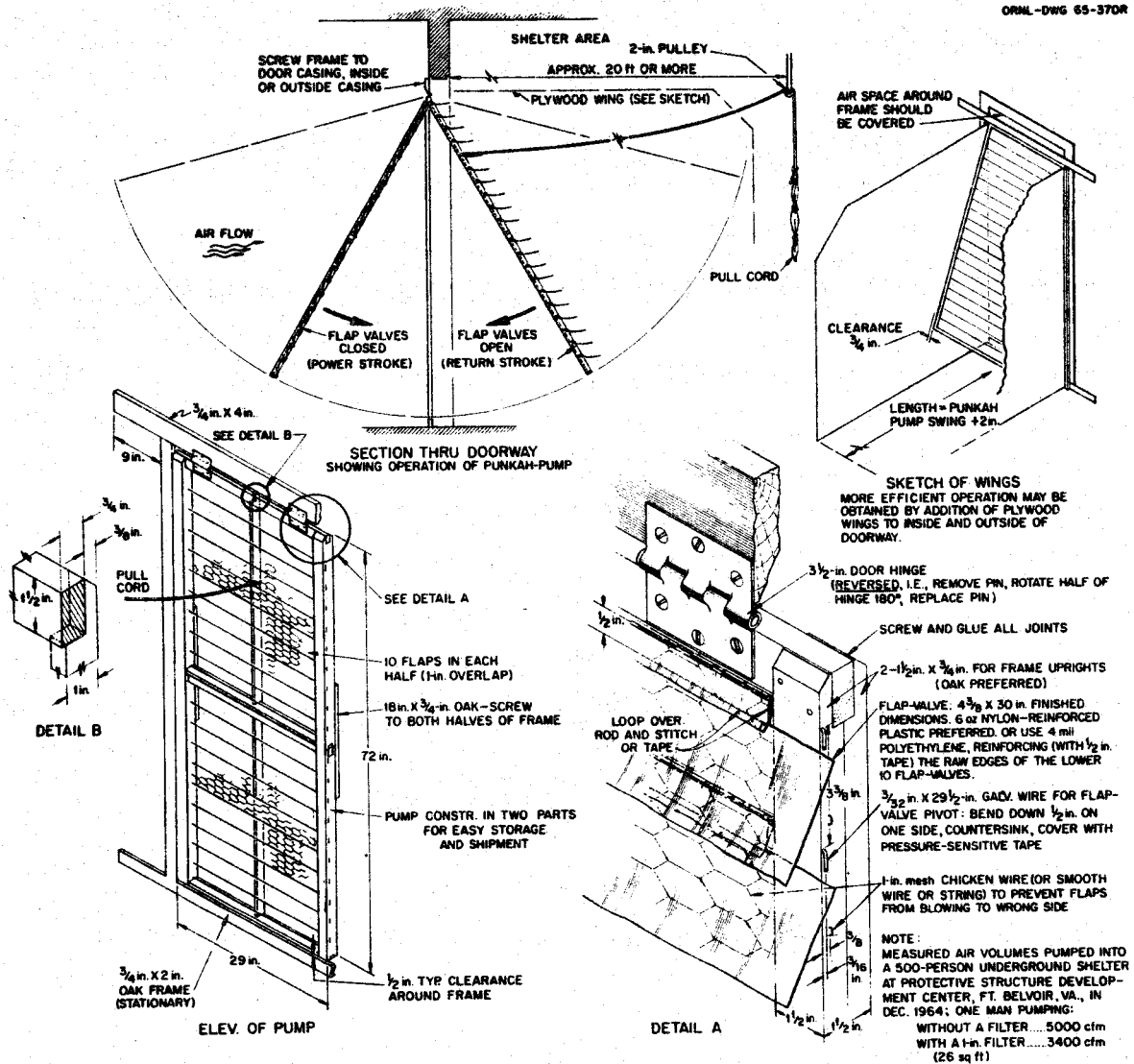


Fig. 1. Punkah-Pump.

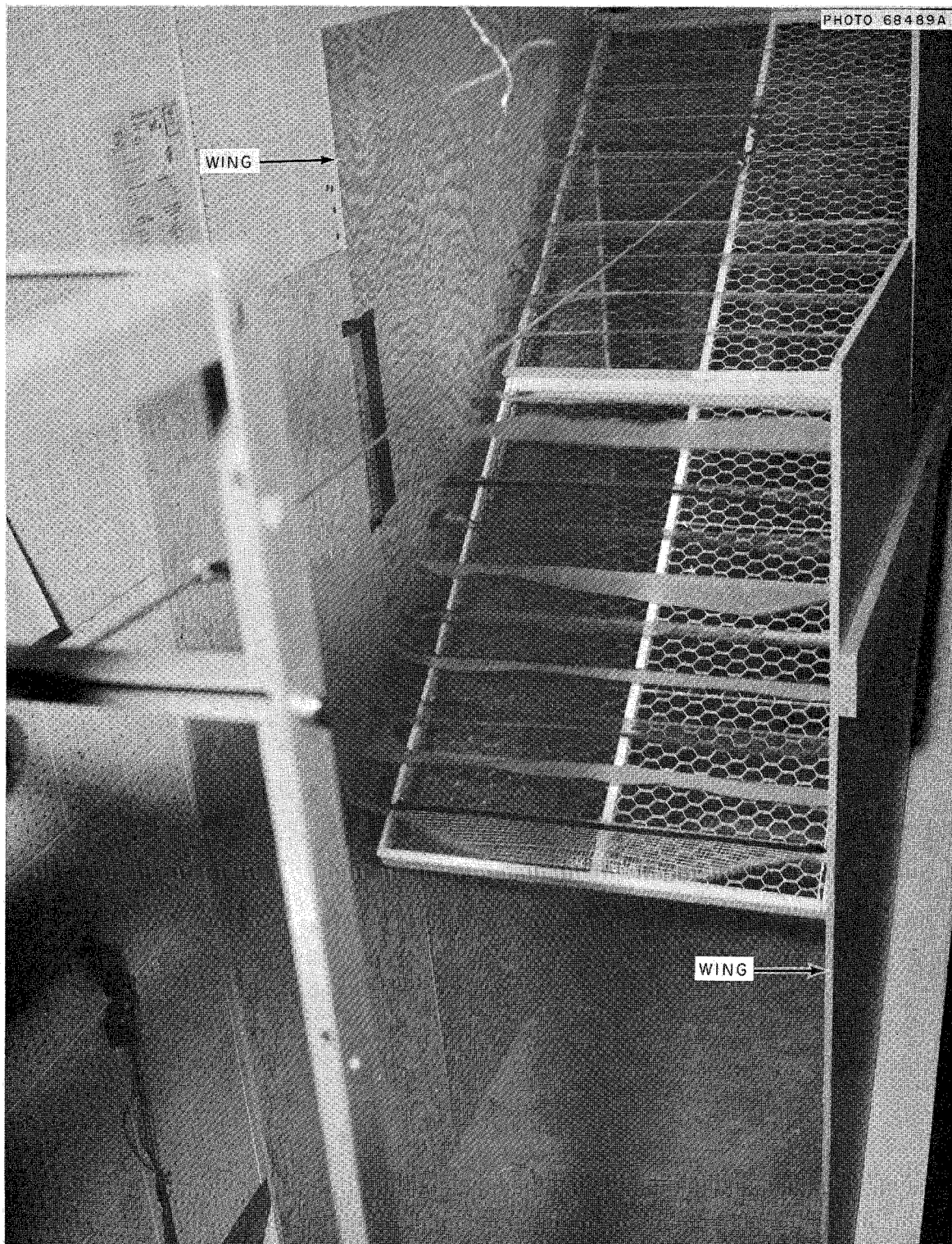


Fig. 2. A six-foot punkah-pump undergoing 1000-hour mechanical durability test, showing flap-valves open during return swing.

ASHRAE Guide,² indicated that 40 times as much work is required to pump 500 cfm through a 3-sq-ft opening as through a 15-sq-ft doorway.

2. The work required to operate the pump should be kept to a minimum, not only to conserve human energy, water, and food during the shelter period but to minimize the extra heat produced by men operating the pump. For since the human body is only about 20% efficient, even if only 0.1 hp is required to operate a large-volume pump, $5 \times 0.1 = 0.5$ hp, or 1273 Btu per hour are added to the heat load of the shelter--equivalent to adding three resting occupants each producing 400 Btu per hour of body heat. (Essentially all the work imparted to the pumped air degrades to heat energy within the shelter and thus contributes to this added heat load.)

3. The air should not be repeatedly accelerated and decelerated, as is done by a conventional piston pump, but the pump should be designed so that the flow of air in the desired direction is continuous and as much as possible of all kinetic energy imparted to the air is utilized to overcome the resistance of the passages to air flow. As can be seen from Fig. 1--drawing of a recently designed punkah-pump--this reciprocating pump allows the air to move continuously in the pumped direction.

2. The Punkah-Pump

2.1 Construction and Operation

As shown by Fig. 1, a punkah-pump utilizes almost the entire cross-sectional area of the doorway or other air intake opening in which it is operated. During the power stroke (or power swing) of this pendulum-like pump, the hinged flap-valves which cover almost its entire surface are closed, and these flap-valves push air in front of them and "suck" air behind them into the shelter. During the return swing, all the flap-valves are open, thus permitting the inertia of the flowing air stream to cause continuous air movement into the shelter, even while the punkah-pump is swinging in the opposite direction.

²ASHRAE Guide and Data Book, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., New York, 1961, pp 161-4.

The 72-in.-by-29-in. punkah-pump illustrated enabled one person, working like a bell toller and at a rate of less than 0.1 hp, to pump over 5000 cfm into the 5000-sq-ft, belowground shelter room at the Protective Structures Development Center, Fort Belvoir, Virginia. During this test in December 1964, this punkah-pump was attached to the door casing of the doorway leading into the shelter from the stairway which served as the air intake passageway. The second stairway into this same shelter room served as the air exhaust passageway--also with its door open to the outside air.

Numerous air-flow measurements across the intake stairway determined the net air pumped into the shelter to be:

- a. without a filter: 5089 cfm
- b. with a 1-in.-fiberglass filter placed across the intake stairway passage: 3440 cfm (The area of the filter was 25.4 sq ft; at the measured rate of flow, the rated resistance of this filter, which costs about 15¢ per sq ft, was about 0.02 in. of water, or about 0.00072 lb per sq in. The advantage of using large areas of filter is obvious!)

During these tests, two "wings" (see Fig. 1) of 6-mil polyethylene on light frames were used on the inside of the doorway. These two "wings" were fixed parallel to the two parallel sides of the volume occupied by the swinging punkah-pump with $3/4$ in., or slightly more, of clearance on each side. More rigid wings, made of plywood, boards, or doors, would have served even better as the near equivalent of the cylinder walls of a piston pump.

If an additional two similar "wings" had been placed on the intake side of the punkah-pump frame, the volume of air pumped would have been further increased.

One way to suspend the pull-cord pulley ideally (6-1/2 ft off the floor and exactly on the centerline of the swing of the pump) is to make a tripod of three boards. If the three top ends are drilled and tied and the three bottom ends on the floor are connected with a rope to keep them from spreading, then such a tripod can support the pull-cord pulley excellently in any shelter.

2.2 Simplified Constructions

The punkah-pump illustrated is made of two directional-punkahs bolted together. Obviously the whole 6-ft frame can be made as a single unit. Also, if a punkah-pump is to be made to operate in a particular shelter door, a pump built the full size of the doorway (less 1/2-in. clearance all around) will pump more air and will make it unnecessary to build a rectangular wooden stationary pump frame, which is only required for a punkah-pump designed to fit in almost any doorway (see Fig. 1).

Once a pump-builder understands basic pump principles, he can make different successful designs of punkah-pumps and directional-punkahs using a wide variety of materials.

For example, for the swinging hinged frame, one can use a simple frame such as that of an ordinary window screen made of 3/4-by-2-in. boards, with an additional vertical 1-by-3/4-in. center stick added, to which the pull-cord can be tied and the wires described below can be fixed. Across the inner face of this frame can be stapled or nailed the hinge wires of the flap-valves. And instead of chicken wire to stop the flap-valves from turning to the wrong side of the moving frame, light smooth wires, or even strings, can be attached to the inner face of the frame. These flap-stopping wires should be stretched parallel to the hinge wires of the flap-valves and spaced about 3/4 in. apart. The weight of such a swinging frame should be increased so that the return swing is lengthened. Such weighting is accomplished most easily by nailing additional boards on the backs of the two vertical wooden sides of the frame.

For hinges one can use metal links, leather, fabric, or cords. And if a pulley cannot be obtained, then, after attaching the pull-cord to a point farther from the hinge-line than when using a pulley, a punkah-pump can be pulled directly by a long pull-cord.

2.3 Durability Tests

A 6-ft punkah-pump has undergone a satisfactory durability test, motor-powered while pumping 4000 cfm into a room for over 1000 hours. It was found that ordinary 2-in. nylon pulleys last for only about two

weeks of continuous use but that 2-in. Delrin (DuPont) pulleys made by Allen-Jervis Marine, Hicksville, New York, show little wear after two weeks. On the lower half of this punkah-pump, flap-valves made of 4-mil polyethylene needed their cut edges reinforced with cloth or plastic tape and some patching of tears (even masking tape will do) in order to last 1000 hours. Details of the tests are contained in another report.³

2.4 Smaller Punkah-Pumps

A 3-ft-tall directional-punkah (see Section IV) can be used as a small-volume punkah-pump to ventilate even a shelter room which has a doorway for its only opening. It should be placed in the lower half of the doorway, positioned so that its power stroke is directed into the room. Then cooler outside air will be pumped into the room, flowing near the floor, while warmer stale air flows out of the room through the unobstructed upper half of the doorway.

IV. DIRECTIONAL-PUNKAHS

1. Purposes and Operation

A directional-punkah is a device almost identical to the pendulum-like swinging frame of a punkah-pump (Fig. 1). It has no "wings" nor enclosures around it and is usually most practical if made only about three feet long. Directional-punkahs are hung from the ceiling and are simple, inexpensive, efficient, manual air-moving devices which enable occupants of crowded shelters, with less than 5% of them working at any one time, to:

- a. Fan all occupants' entire bodies, producing air velocities of 50 to 250 feet per minute. These are sufficiently high air velocities to evaporate practically all sweat on the near-nude

³C. H. Kearny, Mechanized Durability Tests of a Six-Foot Punkah-Pump, ORNL-TM-1155 (June 11, 1965).

bodies of shelter occupants, even if the shelter air reaches effective temperatures several degrees higher than 85°F.*

- b. Eliminate the need within the shelter for air ducts, which are costly in dollars, wasteful of ventilating-pump energy, heat-producing, and space-consuming. A line of directional-punkahs can move many thousand cubic feet per minute. During the power stroke, while their light plastic flap-valves are closed, directional-punkahs push and "suck" air in the desired direction. During the return stroke, their open flap-valves permit almost all the moving air to continue flowing in the desired direction.
- c. Distribute efficiently the air pumped into the shelter, so that effective temperatures are kept approximately the same throughout the shelter and so that all occupants receive their fair share of the outside ventilating air. Temperature differences between top and lower bunks (often amounting to 3 to 5°F even during hot weather in conventional still-air shelters) can be practically eliminated.
- d. Have a physical, useful outlet for some of the energy and tension of shelter occupants by providing them with obviously useful light work which often would contribute to their survival and usually to their comfort. The work rate required to operate a steel-framed 36-by-29-in. directional-punkah is only about 0.007 hp.**

* Preliminary physiological tests conducted by the writer in a specially insulated shelter test room (which necessitated essentially all body heat being dissipated by the evaporation of sweat) showed that, when the above-specified ventilation requirements for hot summer conditions were met, then, during the 9-1/2 hottest hours of a one-percentile New York summer day, the effective temperatures throughout the shelter averaged 84.4°F, while the effective temperatures of the entering air averaged 82.6°F. Simultaneously, the average dry bulb temperatures within the shelter were lowered to 89.3°F, as compared to an average entering air temperature of 91.2°F--due to the efficient evaporation of almost all the test subject's sweat on his skin. The temperature of his stomach skin averaged 91.9°F and oral temperature, 98.9°F.

** To determine the horsepower required for the manual operation of such pulled devices, a motion picture camera which takes a known number of picture frames per second was used to record a series of instantaneous

2. Construction and Installation

The swinging part of the 6-ft punkah-pump illustrated in Fig. 1 is made by connecting two directional-punkahs of the best wooden design and the best size (36 by 29 in.) developed to date--except that for use as a punkah-pump, thicker flap-valves were used. The flap-valves of a directional-punkah are best made of polyethylene about 3 mils thick. Simpler models, more easily built in a home workshop, can be made by using the same techniques previously mentioned in regard to building simpler punkah-pumps.

A 36-by-29-in. directional-punkah is best pulled by a cord connected to its frame at a point on its centerline and about 9 inches below the horizontal line of its hinges. For operating directional-punkahs which are hung overhead, it is advantageous to run the pull-cord over a 2-in. pulley positioned a few inches below the height of the hinge line. Then the operator can do his work with an easy downward pull, like a bell toller. One pull-cord can be used to swing three or four identical directional-punkahs, if they are hung in a straight line, preferably at the same height and about 15 feet apart.

If a directional-punkah has a steel frame, built to minimize its resistance to movement through the air flow during its return stroke, then it will be even more efficient than a good wooden one.

V. CONCLUSIONS AND RECOMMENDATIONS

1. It is practical, with manual ventilating devices as efficient as punkah-pumps and directional pumps, to maintain tolerable conditions in crowded, long-occupied shelters cooled only by outside air. During

pull-cord stresses measured by a spring-scale inserted between the hand-grip and the pull-cord. A boldly marked rule was placed nearby and parallel to the line along which the pull-scale reciprocated; thus, the high-speed photographs also recorded the distance pulled during each time interval between frames. From these data for one complete cycle, a curve was plotted showing pounds pulled at each pictured instant, and also at each of these instants the distance pulled, measured from the beginning of the cycle. The area under this curve represented work, and, from the time per cycle, horsepower could be readily calculated.

hot weather in those parts of the country which experience the worst humid heat conditions, three requirements must be met:

- a. Sufficient outside air must be pumped into the shelter--up to 30 cfm per occupant under the worst conditions.
- b. The air must be properly distributed within the shelter.
- c. Moving-air conditions must be maintained over the bodies of the shelter occupants, and sufficient water (up to 5 quarts per day per person) and salt ($1/3$ ounce) must be provided.

2. If approved public shelters and hastily constructed shelters were thus equipped, so that they would be habitable at their rated capacities even during summer heatwaves, then not only could more lives be saved in the event of an attack during warm weather, but also public support of civil defense, based on the public's belief in its effectiveness, should be strengthened.

3. In shelters thus equipped, it appears probable that future practical tests will demonstrate that considerably less than 10 sq ft of floor space per occupant is required, especially if open-mesh hammocks or special bunks are provided.

4. Practical tests should also explore the possibilities not only of thus being able to shelter more people in high-protection-factor below-ground shelters, but also of being able during the hours of worst fallout danger to concentrate shelter occupants in those parts of low-protection-factor shelters which offer the best protection and through which cooling air flows could be maintained by directional-punkahs.

5. These efficient devices for manually ventilating shelters would improve the practicality of using shelters as barracks after the end of the shelter period, in order to minimize exposure to continuing radiation, to concentrate workers near their jobs during a period of fuel and transportation shortages, and to expend less labor and materials on housing and decontamination at a time when it would be advantageous first to concentrate on the restoration of productive facilities and essential services.

In this type of shelter and in other shelters which depend on electric power for ventilation, punkah-pumps and directional-punkahs can be considered stand-by ventilation systems to reduce the dependence of shelters on public or auxiliary power.

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